

KURATITE (IMA 2013-109): THE “UNKNOWN” Fe-Al-Ti SILICATE FROM THE ANGRITE D’ORBIGNY. Hwang S-L¹, Shen P², Chu H-T³, Yui T-F⁴, Varela M.E⁵ and Iizuka Y⁴, ¹Department of Materials Science and Engineering, National Dong Hwa University, Hualien, Taiwan, ROC (slhwang@mail.ndhu.edu.tw); ²Department of Materials and Optoelectronic Science, National Sun Yat-sen University, Kaohsiung, Taiwan, ROC; ³Central Geological Survey, PO Box 968, Taipei, Taiwan, ROC; ⁴Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, ROC; ⁵Instituto de Ciencias Astronómicas de la Tierra y del Espacio (ICATE) Avenida España 1512 sur, J5402DSP, San Juan, Argentina

Introduction: Angrites are a fascinating group of achondritic meteorites, the petrogenesis of which has been, and still is, a matter of ongoing debates. The chemical composition of angrites is peculiar with high abundances of refractory lithophile elements and low abundances of siderophile and volatile elements. Its unusual composition is reflected in their odd mineralogy. Here we report a detail mineralogical study of one such rare mineral: the Fe-Al-Ti-Si phase from the angrite D’Orbigny that has been recently approved as a new mineral (kuratite) by the CNMNC.

KURATITE (IMA 2013-109): $\text{Ca}_{1.954}(\text{Fe}^{2+}_{4.871}\text{Fe}^{3+}_{0.481}\text{Ti}_{0.648})(\text{Si}_{3.931}\text{Al}_{1.777}\text{Ti}_{0.358})\text{O}_{20}$. The name Kuratite was given in honor of Professor Dr. Gero Kurat (1938 - 2009), former Head of the Mineralogical-Petrographical Department and Curator of the Meteorite Collection at the Natural History Museum in Vienna, Austria. He identified the unusual D’Orbigny meteorite as an angrite.

Kuratite belongs to the aenigmatite-rhönite mineral group. The presence of dominant Fe^{2+} in octahedral sites warrants its status as a new mineral [1].

Analytical method: For the purpose of determining the unit cell parameters of kuratite by electron crystallography, two transmission electron microscopy (TEM) thin sections were prepared by the focused-ion-beam (FIB) technique. Single-crystal X-ray studies were carried out using electron diffraction. Selected area electron diffraction (SAED) patterns were obtained from micrometer-sized kuratite crystals using a JEOL 3010 AEM. The error of the d spacing measurements on SAED patterns taken at a camera length of 120 cm and calibrated by Al standard was estimated to be ± 0.002 nm.

Sample and Results: The PTS used for this study was kindly loaned by the Naturhistorisches Museum Wien, Austria (inventory number: Section D’Orbigny C-N1172-NH Wien).

The studied Kuratite crystals typically are euhedral to anhedral in shape, $< 20 \mu\text{m}$ in size, and occur, along with whitlockite and submicrometer-sized Fe sulfide droplets, within a rim of olivine with Ca-rich fayalite composition (Ca ~ 20 mol%) + kirschsteinite (Ca ~ 40 mol%) intergrowths at the contact between Fe sulfide spherules and the space-filling hedenbergite (Fig. 1).

For the purpose of microstructure analysis, two TEM samples of dimensions $5 \mu\text{m} \times 5 \mu\text{m} \times 100 \text{nm}$

were prepared by FIB from two kuratite grains (inserts in Figure 1 B).

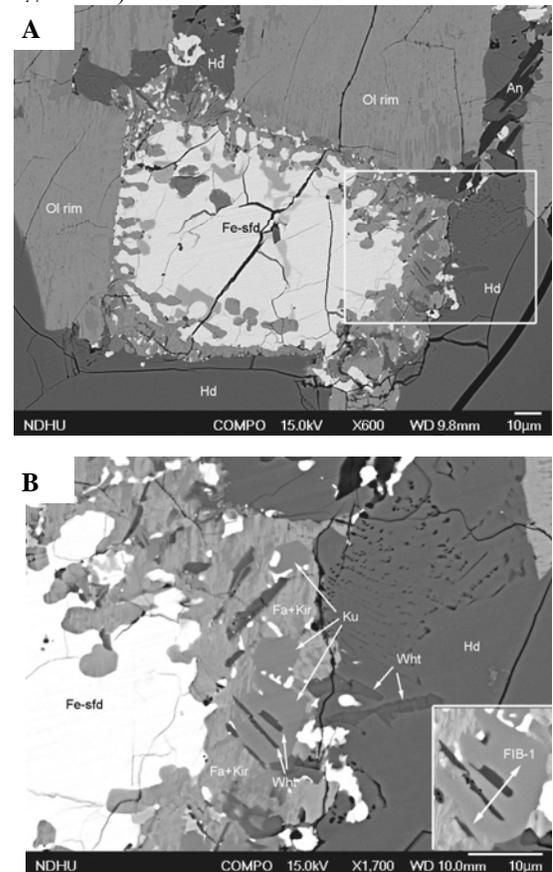
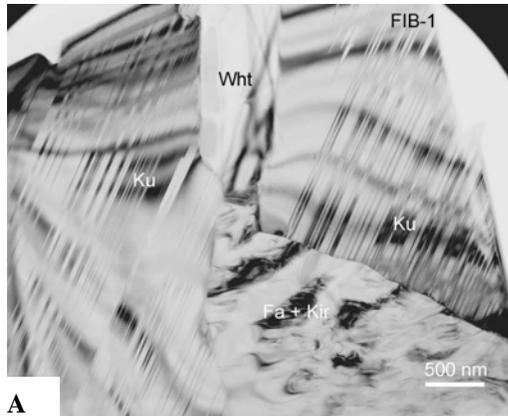


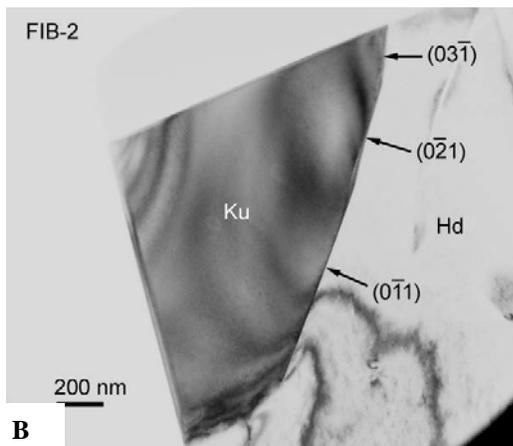
Figure 1: A-B) SEM-BSE micrographs showing kuratite (Ku) and whitlockite (Wht) crystals surrounded by Fe/Ca-olivine intergrowth at the periphery of Fe sulfide spherules. The inset in B) indicate the site for an FIB thin section for electron diffraction study.

SAED patterns of kuratite and inclusions were taken at various tilt angles for phase identification. A representative TEM bright field micrograph showing a kuratite crystal with abundant polysynthetic nano-twins and whitlockite inclusions in thin section FIB-1 is shown in Fig. 2A. The twin plane is $(0\bar{1}1)$, similar to that reported for other aenigmatite-rhönite group minerals. In contrast, the kuratite crystal in thin section FIB-2 is twin-free and inclusion-free, and is associated with euhedral whitlockite and a rounded Fe sulfide droplet

within a polycrystalline herdenbergite matrix (Fig. 2B). Kuratite is faceted by small faces, such as $(0\bar{1}1)$, $(0\bar{2}1)$ and $(03\bar{1})$ etc., as indicated in Figure 2-B.



A



B

Figure 2: A-B) TEM bright field images showing (A) kuratite (Ku) crystals in thin section FIB-1 with abundant polysynthetic $(0\bar{1}1)$ nano-twins, associated with whitlockite inclusions and Fe/Ca-olivine intergrowth matrix, and (B) the twin-free kuratite crystal with $(0\bar{1}1)$, $(0\bar{2}1)$ and $(03\bar{1})$ facets in thin section FIB-2, with the associated euhedral whitlockite crystals.

The first description of this rare phase was done by [2] reporting the discovery of an unknown Fe-Al-Ti-silicate, characterized by a cation/Si ratio of ~ 2.65 . Kurat et al [3] found the unknown Fe-Al-Ti silicate in multi-phase inclusions in anorthite, forming euhedral crystals of up to 20 μm in diameter. This unknown phase is also enclosed by augite and associated with magnetite, troilite and kirschsteinite. Its major chemical composition is homogeneous [2-3] and is characterized by high and unfractionated REE ($\sim 100 \times \text{CI}$)

contents [4]. More recently this mineral was found in the angrite NWA 4590 and identified as rhönite [5]. Comparisons of D'Orbigny and SAH 99555 rhönites with that from the angrite NWA 4590 indicates a slightly different chemistry, in particular the absence of Fe^{3+} and Cr^{3+} , and the Si, Al deficiency in the tetrahedral site [6].

Rhönite is the only aenigmatite-rhönite group minerals reported to include compositions with $\text{Mg}^{2+}/(\text{Mg}^{2+}+\text{Fe}^{2+}) < 0.5$ and $\text{Mg}^{2+}/(\text{Mg}^{2+}+\text{Fe}^{2+}) > 0.5$. Recalculations gave $\text{Mg}^{2+}/(\text{Mg}^{2+}+\text{Fe}^{2+}) = 0.156-0.499$ for several terrestrial rhönites [e.g., 7-8] and $\text{Mg}^{2+}/(\text{Mg}^{2+}+\text{Fe}^{2+}) = 0.17$ and 0.03 , respectively, for "rhönite" from NWA 4590 angrite [5] and Luna 24 regolith [9]. These "rhönites" with $\text{Mg}^{2+}/(\text{Mg}^{2+}+\text{Fe}^{2+}) < 0.5$ could be categorized into a new kuratite subgroup with the characteristic end-member composition $\text{Ca}_4(\text{Fe}^{2+}_{10}\text{Ti}_2)\text{O}_4[\text{Si}_8\text{Al}_4\text{O}_{36}]$.

The Raman spectrum of kuratite shows four main scattering peaks near 563-571, 697-699 (strongest), 852-856 and 986-996 cm^{-1} resembling that of lunar rhönite [9]) but with higher frequencies due to different chemical composition (Fig.3).

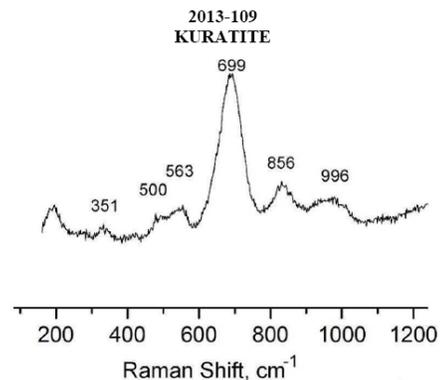


Figure 3: Representative Raman spectrum of Kuratite.

References: [1] Nickel E.H. and Grice J.D. (1998) *Canadian Mineralogist* **36**, 913-926; [2] Mittlefehldt et al. (2002) *Meteoritics and Planetary Science* **37**, 345-369; [3] Kurat et al., (2004) *Geochimica et Cosmochimica Acta* **68**, 1901-1921; [4] Varela et al., (2005) *Meteoritics and Planetary Science* **40**, 409-430; [5] Kuehner S.M. and Irving, A.J. (2007) *Eos Trans. AGU* **88**, Abst P41A-0219; [6] Jambon A. and Boudouma O. (2011) *Meteoritics and Planetary Science Suppl.* # 5167; [7] Grew E.S. et al. (2008) *Mineralogical Magazine* **72**, 839-876; [8] Grapes K. and Keller J. (2010) *European Journal of Mineralogy* **22**, 285-292; [9] Treiman A.H. (2008) *American Mineralogist* **93**, 488-491.